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SWIMMER LIFE SUPPORT SYSTEM (SLSS MK 1) TECHNICAL EVALUATION.(U)
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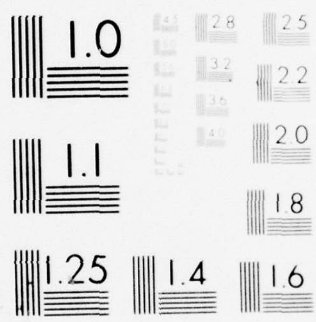

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PANAMA CITY, FLORIDA 32407

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3 March 1977

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3 March 1977

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SLSS MK1 Evaluation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Technical evaluation of the Swimmer Life Support System (SLSS MK 1) including unmanned, manned and open sea testing. Compares required technical and operational characteristics with TECHEVAL results. Concludes the system is ready for Operational Evaluation.

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c. NAVY EXPERIMENTAL DIVING UNIT REPORT NO. 9-72

d. NAVY EXPERIMENTAL DIVING UNIT REPORT NO. 7-75

e. NAVSEA CONTRACT NO. N00024-76-C-4167

f. TEST AND EVALUATION MASTER PLAN 098-1

g. CNO MESSAGE C061834Z MAY 76 (NOTAL)

h. SOR 38-02 (C)

GLOSSARY

ABORT	Premature termination of working dive after completion of setup, wet checkout, and approval of Diving Officer to start the dive. Aborts caused by factors external to the SLSS MK 1 Diving System will not be considered in computing mission or life support reliability.
A_O	Operational Availability
BARALYME	CO_2 Absorbent
BPM	Breaths Per Minute
BOTTOM TIME	Elapsed dive time from leaving the surface to leaving the bottom.
CO_2	Carbon Dioxide Gas
FSW	Feet of Seawater
HAZARD	Any real or potential condition that can cause injury or death to personnel, or damage to or loss of system.
HAZARD LEVEL	A qualitative measure of the degree to which a given failure represents a hazard to personnel and/or equipment. <u>NEGLIGIBLE</u> . . . will not result in personnel injury or system damage. <u>MARGINAL</u> . . . . can be counteracted or controlled without injury to personnel or major system damage. <u>CRITICAL</u> . . . . will cause personnel injury or major system damage, or will require immediate corrective action for personnel or system survival. <u>CATASTROPHIC</u> . . will cause death or severe injury to personnel or system loss.
HeO_2	A mixture of helium and oxygen used as a breathing gas.

LIFE SUPPORT RELIABILITY (R_L)	The probability that, after system checkout, including diver's entry into water and Diving Officer's approval to start the dive, the life support system will carry the diver through his intended mission without abort due to critical or catastrophic hazard levels attributable to a life support system malfunction or design deficiency.
LSI	Logistic Support Index
MATERIAL SUITABILITY TERMS	For the purpose of this project, the following definitions apply: (a) Critical Failure - Equipment is inoperative. No performance, or a critical or castastrophic hazard level exists. (b) Major Failure - Equipment is operable at a reduced level of effectiveness. A malfunction exists, performance is affected but the system can be used. (c) Minor Failure - The equipment is operable. Minor discrepancies exist but do not affect equipment performance.
MISSION	Scheduled dive together with assigned task, test or procedures.
MISSION RELIABILITY (R_M)	The probability that, after system checkout, including diver's initial entry into water and Diving Officer's approval to start the dive, the system will carry the diver through his intended mission without abort attributable to a system malfunction or design deficiency.
MTBF	Mean Time Between Failures
MTFL	Mean Time For Fault Location
MTTR	Mean Time To Repair
O.B.	Over Bottom
OSF	Ocean Simulation Facility
OPERATING TIME	Time during which the equipment is operating to specified standards in any mode for which it was designed. Minor faults may exist that do not significantly affect the equipment's ability to fulfill specified standards.

ΔP	Pressure Differential
PPO_2	Partial Pressure of Oxygen
PREDIVE TIME	The time during which the Diving System is actively undergoing predive checkout.
POST-DIVE TIME	The time during which the Diving System is actively undergoing post-dive checkout.
psi	Pounds per square inch.
psid	Pounds per square inch of differential pressure.
psig	Pounds per square inch, gauge.
S.E.	Surface equivalent.
REACTION TIME (T_R)	Time required to make preparations for the first dive of the day. T_R commences when diving station is fully manned and concludes when first diver commences his dive.
TURNAROUND TIME (T_T)	Time from completion of a dive to the time the same system is ready for a subsequent dive. Includes doffing, donning and system-predive checkout times.

FIGURE 1. FRONT VIEW OF SLSS MK 1

FIGURE 2. BACK VIEW OF SLSS MK 1

FIGURE 3. RIGHT SIDE VIEW OF SLSS MK 1

FIGURE 4. LEFT SIDE VIEW OF SLSS MK 1

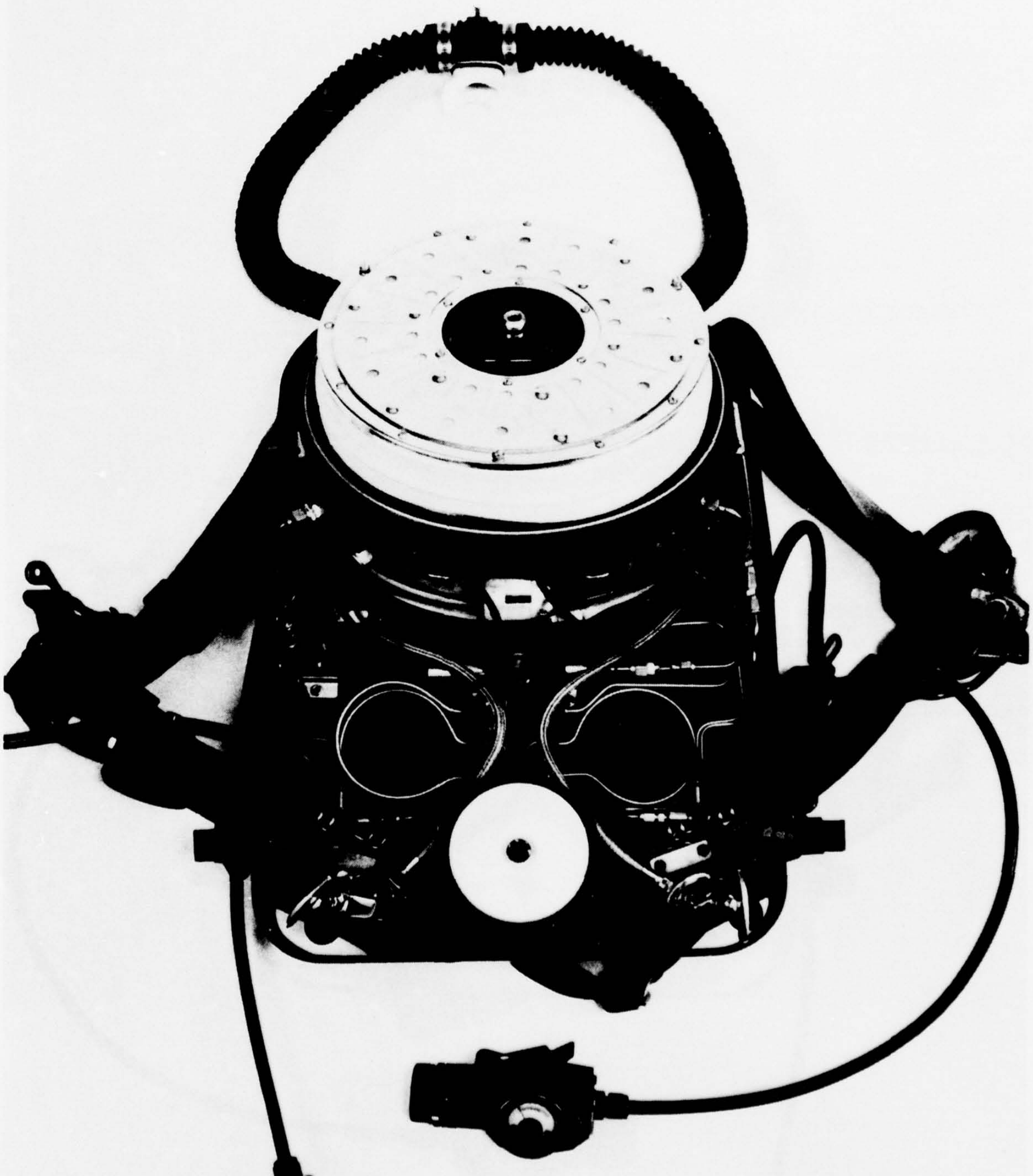


FIGURE 5. INTERNAL VIEW OF SLSS MK 1 (NO BOTTLES INSTALLED)

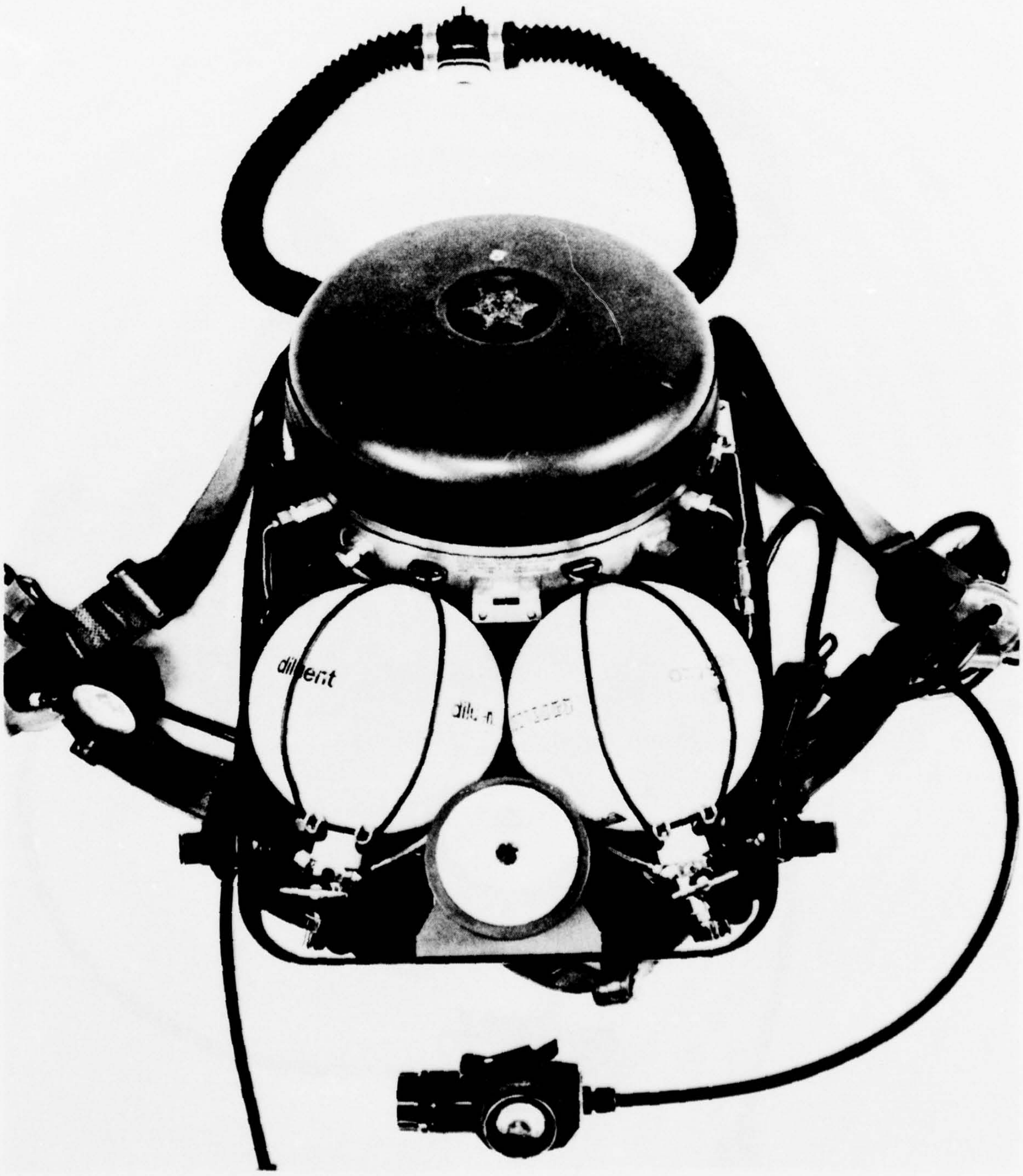


FIGURE 6. INTERNAL VIEW OF SLSS MK 1 (BOTTLES INSTALLED)

SLSS MK 1 SCUBA

TECHEVAL REPORT

Section 1

INTRODUCTION

1.1 Background. The purpose of this project, designated CNO Project 098-1, is to evaluate the Swimmer Life Support System (SLSS) MK 1. Through prior testing in the form of fleet assists, it had been established that the MK 1 closely met the requirements for a closed-circuit, mixed-gas SCUBA called for in SOR 38-02. The data gathered during those earlier tests are reported in references b, c, and d. Several modifications to the original unit were directed by NAVSEASYSCOM and complied with by the manufacturer. Because these modifications involved some of the vital capacities of the unit, further testing was necessary. Therefore, formal technical and operational evaluations are being conducted to establish whether the MK 1 meets the diver life support requirements of the Special Warfare community.

General Characteristics of the SLSS MK 1

- State-of-the-art materials and production techniques.
- Complete interchangeability of parts.
- Reduced overall unit weight.
- Corrosion-resistant materials.
- Modular replacement of parts.
- Increased bottom time.
- Increased diver safety.

Support Equipment

- Maintenance Tool kit.
- Spare parts.

With the above features the SLSS MK 1 is a major equipment improvement for the combat swimmer and the U.S. Navy.

1.2 Description of Unit. The SLSS MK 1 SCUBA is a closed circuit, mixed gas SCUBA that electronically controls the partial pressure of oxygen in the breathing medium. The unit employs a scrubber containing

Baralyme as a carbon dioxide absorbent, giving the unit its rebreather capability. The MK 1 is comprised of 4 sub-assemblies as follows:

a. Backpack

b. Breathing Loop

c. Pneumatics

d. Electronics

The backpack serves as a base to which all other sub-assemblies are secured. It also serves as the anchor for the one-point release harness which secures the unit to the diver's body. A cover serves to isolate any components that could cause fouling of the unit and to present a hydrodynamic shape to the water.

The breathing loop consists of a ball valve mouthpiece and check valves, an exhalation hose, a scrubber housing, a CO_2 scrubber, moisture absorbers, a diaphragm or counterlung, and an inhalation hose. Located on the diaphragm is an exhaust valve that allows any excess gas in the breathing loop to be dumped to sea.

The pneumatics sub-assembly is comprised of an oxygen cylinder and diluent cylinder, reducing regulators, manual bypass valves, automatic gas addition valves, and cylinder pressure gauges. All of the above components are connected with either stainless steel tubing, stainless steel flex hose or flexible, synflex-type hose. Four types of connectors are used: CPV, Swagelock, pipe (NPT), and silver soldered. The type of connector used was determined by the frequency of its disassembly.

The unit's electronics sub-assembly is comprised of an on-off switch, a main electronics module, a disposable alkaline-manganese battery, a solenoid valve, three galvanic action oxygen sensors, a primary wrist display, and a secondary display. The electronics contained in the MK 1 make it unique when compared with SCUBAs presently used by Special Warfare commands. The sensors constantly monitor the partial pressure of oxygen in the breathing loop. The signals from the sensors provide the inputs to the electronics module where they are averaged and then compared to a predetermined set point. When the sensor signal average is lower than the set point, the electronics module signals the solenoid valve to actuate, admitting approximately 1/3-liter of oxygen to the breathing loop. This action continues until the sensor signal average is equal to the set point. The solenoid valve then remains shut until the diver consumes the O_2 in the loop to the point of creating a difference between the sensor signal average and the set point. Conversely, if the average signal from the sensors is higher than the set point the solenoid valve

will not open until the partial pressure of oxygen in the loop is brought down below the set point. This would be accomplished by the diver's metabolic oxygen consumption. In order to keep the diver informed as to the breathing loop status, the primary wrist display has several lights indicating various levels of oxygen relative to the set point partial pressure. Additionally, the secondary display indicates the individual signal of each sensor to permit the diver to evaluate a malfunction should one occur.

1.3 Physical Characteristics.

1.3.1 Buoyancy + 1.5 lbs. (+ .68 Kg) in salt water

1.3.2 Dimensional Envelope - LENGTH 23-1/2 in. (59.6 cm), WIDTH 15-3/4 in. (40 cm), DEPTH 10-1/2 in. (26.6 cm)

1.3.3 Gas flask capacities

1.3.3.1 Oxygen flask - 21 ft^3 (6.4 m^3) at 3000 psig (1360.7 K/m^2)

1.3.3.2 Diluent flask - 21 ft^3 (6.4 m^3) at 3000 psig (1360.7 K/m^2)

1.3.4 Breathing Loop Capacity - 7.39 qts (7 liters)

1.3.5 CO_2 Scrubber Capacity

1.3.5.1 Baralyme - 8.25 LBS (3.74 Kg)

1.3.5.2 Sodasorb - 7.25 LBS (3.28 Kg)

1.4 Previous Deficiencies. The first Biomarine CCR-1000 (SLSS MK 1) test and evaluation period was in March 1972 and is reported in NEDU Report 3-72. A second test was conducted in September 1972 and is reported in NEDU Report 9-72, and a third, conducted in July 1975, is reported in NEDU Report 7-75. The results of these earlier tests indicated the following deficiencies:

a. That the SLSS MK 1 was excessively negative (buoyancy) in sea water.

b. That the sensor leads/connectors are too exposed and therefore susceptible to damage.

c. That the "V" clamp which secures the scrubber assembly is too difficult to manipulate.

d. That the pressure gages tended to be either in the way or not easily accessible.

e. That a hydrostatic overpressure often develops when the diver is in an upright position.

f. That the SLSS MK 1 is not fully compatible with the MK VII SDV.

1.5 <u>Corrective Action</u>. All of the above mentioned items have been corrected except as noted in the paragraphs which follow.

1.5.1 The SLSS MK 1 is not fully compatible with the SDV MK VII. The problem is that the SDV crew members have difficulty reaching the bypass valves. It should be noted that SDV MK VII is expected to be phased out in the future. Testing with the SDV MK IX has shown that the SLSS MK 1 is compatible with it.

1.5.2 The hydrostatic overpressure still occurs occasionally due to the present harness design which does not allow the diver to easily adjust the MK 1 while being worn. Testing with an in-house modified harness has eliminated this problem, in turn minimizing the effect of the overpressure.

Section 2

UNMANNED TESTING

2.1 Objectives. This test series was designed to demonstrate that the SLSS MK 1 can support life through depth/time profiles as outlined in references c, d, e, and f.

The following were test criteria.

a.	Diaphragm Volume	Minimum 7 liters
b.	Breathing Resistance	$\pm$ 15 cm H_2O with Tidal Volume 2 LPB at 20 Breaths per minute
c.	CO_2 Scrubber Duration	6 hrs. in 40°F (4°C) water
d.	End Point for Scrubber Duration Determination	0.5% CO_2 Surface Equivalent
e.	Battery	Provide sufficient power for six hours.

2.1.1 Location. These tests were performed at the Navy Experimental Diving Unit Ocean Simulation Facility (OSF), Panama City, Florida, in March 1976.

2.1.2 NEDU test and evaluation personnel performed the required test, assisted by the Projects Department UDT/SEAL personnel.

2.2 Scope of Testing

2.2.1 Conduct. Testing parameters were established in accordance with most recent standards for life support equipment utilized by NEDU.

2.2.2 Method of Testing. The safe, economical and reliable collection of equipment performance data was achieved utilizing the following approach.

Initially, a comprehensive, unmanned test program was conducted to insure the life support capability of the equipment. In this phase, four SLSS MK 1's were exercised by a breathing machine at various depths from the surface to 200 feet. The MK 1 was submerged in a test tank. Breathing resistance was measured and recorded on an X-Y plotter. The volume per breath and breathing frequency, as simulated by the breathing machine, were varied at each test depth. The entire test cycle was performed a minimum of two times utilizing compressed air as the diluent gas during one cycle and helium-oxygen as the diluent gas on the other.

The data obtained from this test defined the breathing characteristics of the MK 1 under a variety of simulated work loads throughout its intended depth spectrum.

The unmanned test phase also included a determination of the capability and duration of the CO_2 scrubber. With the unit immersed in a test tank, a controlled flow of CO_2 was injected into the breathing loop and normal breathing gas was circulated through the loop by the breathing machine. Sample gas was drawn off at the inhalation hose and analyzed for CO_2 content. When the CO_2 concentration in the sample gas reached 0.5% surface equivalent, "breakthrough" had occurred and scrubber duration was established. Canister duration tests were conducted at water temperatures of 29°F (-2°C), 40°F (4°C), and 70°F (21°C).

Upon completion of the unmanned test phase the collected data were analyzed to determine the life support capability of the equipment.

2.2.3 Test Procedure

a. Breathing machine studies were conducted at the following rates which simulate from light to very hard work rates.

Work Rate	Breathing Rate (BPM)	Tidal Volume (Liters Per Breath)	Respiratory Minute Volume (LPM)
Light	11	2.0	22.0
Moderate	20	2.0	40.0
Hard	31	2.0	62.0
Very Hard	35	2.0	70.0

ΔP within the apparatus and total work of breathing were measured in accordance with the method described in NEDU Report 19-74. These tests were conducted at 0, 33, 66, 99, 132, 170 and 200 FSW (0, 10, 20, 30, 40, 52, 61 m) with PPO_2 being controlled at 0.7 ATA. Data were collected at each depth after the equipment had stabilized. Gas was permitted to pass through the equipment for a minimum of two minutes at each depth. Readings were taken during both the compression and decompression phases of the dive. Each test run, from the surface to 200 FSW (61m) and back to the surface produced 26 data points.

Diluent gases used were air and 80/20 HeO_2 supplied, at 1000 psi over bottom, through an umbilical connected to the diluent regulator; the O_2 bottle was filled with 100% O_2. The PPO_2 was controlled by the equipment's electronics system.

b. Canister breakthrough studies were done using both Baralyme and Sodasorb to gain comparative data between the two absorbents. CO_2 was added at rates of from .8 to 1.5 liters per minute during the canister breakthrough test in both cold 40°F (4°C) and warm 70°F (21°C) water.

Canister breakthrough was assumed at 0.5% S.E. CO_2. Readings were recorded every 30 minutes until the CO_2 level reached 0.4%, then as often as the project officer deemed necessary. This test was done with OSF chamber "D" on the surface using a tank at 40°F (4°C) and 70°F (21°C) as a test environment. Figures 7-10 depict the data acquired during canister duration studies in different water temperatures and using both Baralyme and Sodasorb. Table 1 and Figures 11A-11G provide the data on the unmanned, air tests and Table 2 and Figures 12A-12G provide the same data for the unmanned, HeO_2 tests.

Special Note: A separate report will be issued by the NEDU Medical Department which will explain, in greater detail, those physiological results which were outside the established limits. In brief, however, high breathing resistances, breathing work and CO_2 levels were encountered only at very high RMV's, which could only be sustained for a very short period even by a diver in the best physical condition. The data points in the tables and figures that follow which fall outside of the established limits are no cause for alarm.

SSLS MK 1 SCUBA

SCRUBBER DURATION STUDIES

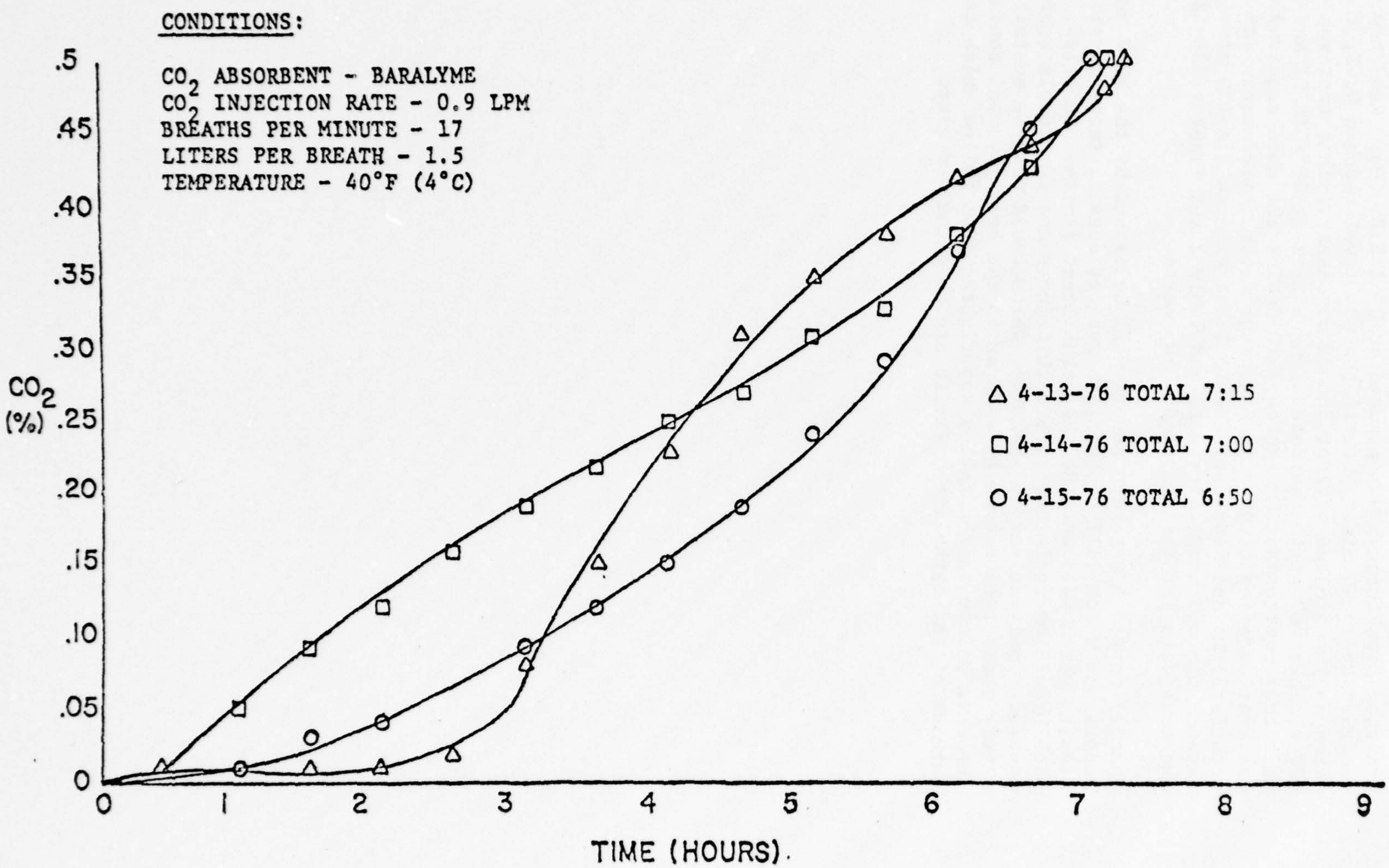


FIGURE 7

SSLS MK 1 SCUBA

SCRUBBER DURATION STUDIES

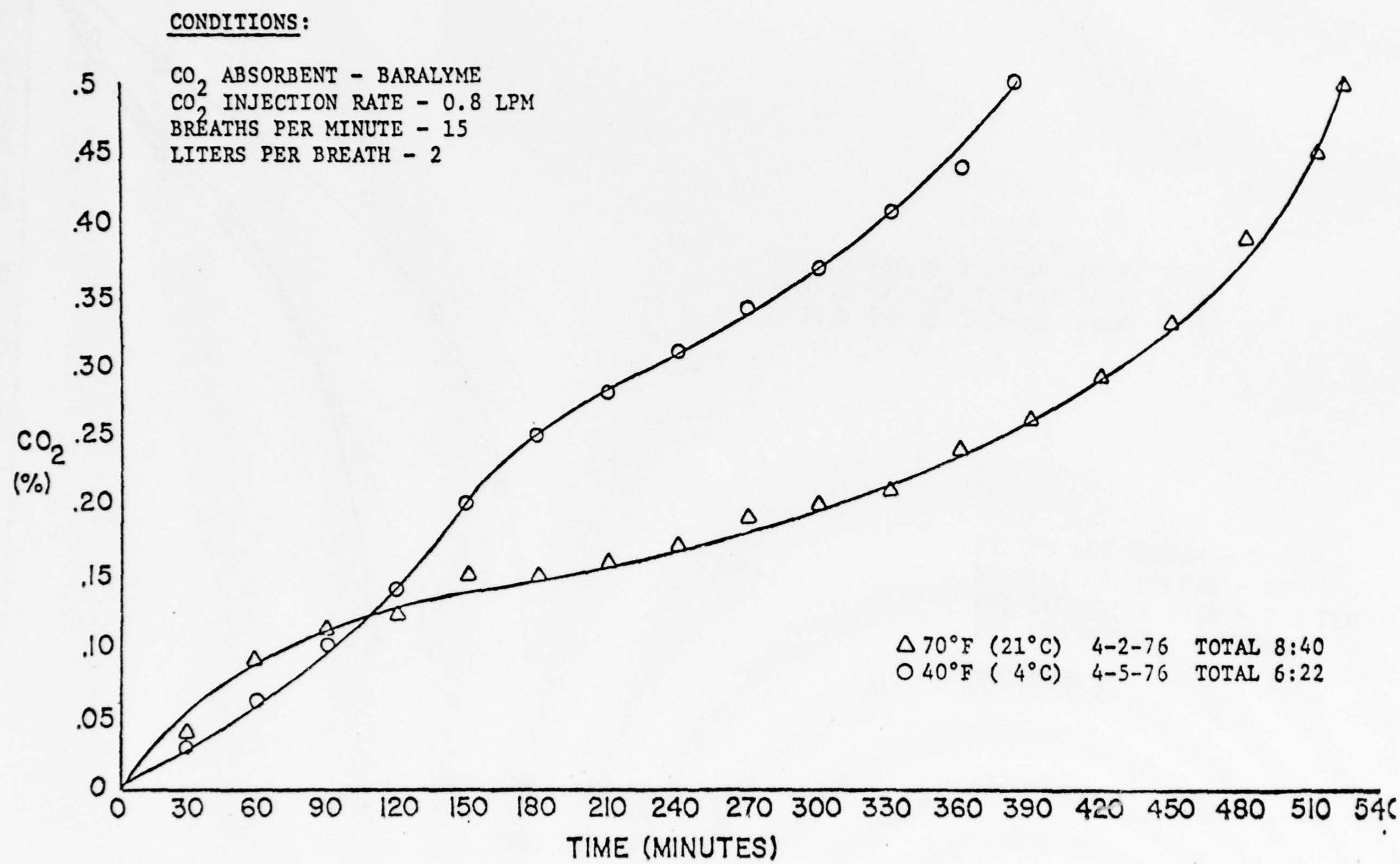


FIGURE 8

SLSS MK 1 SCUBA

SCRUBBER DURATION STUDIES

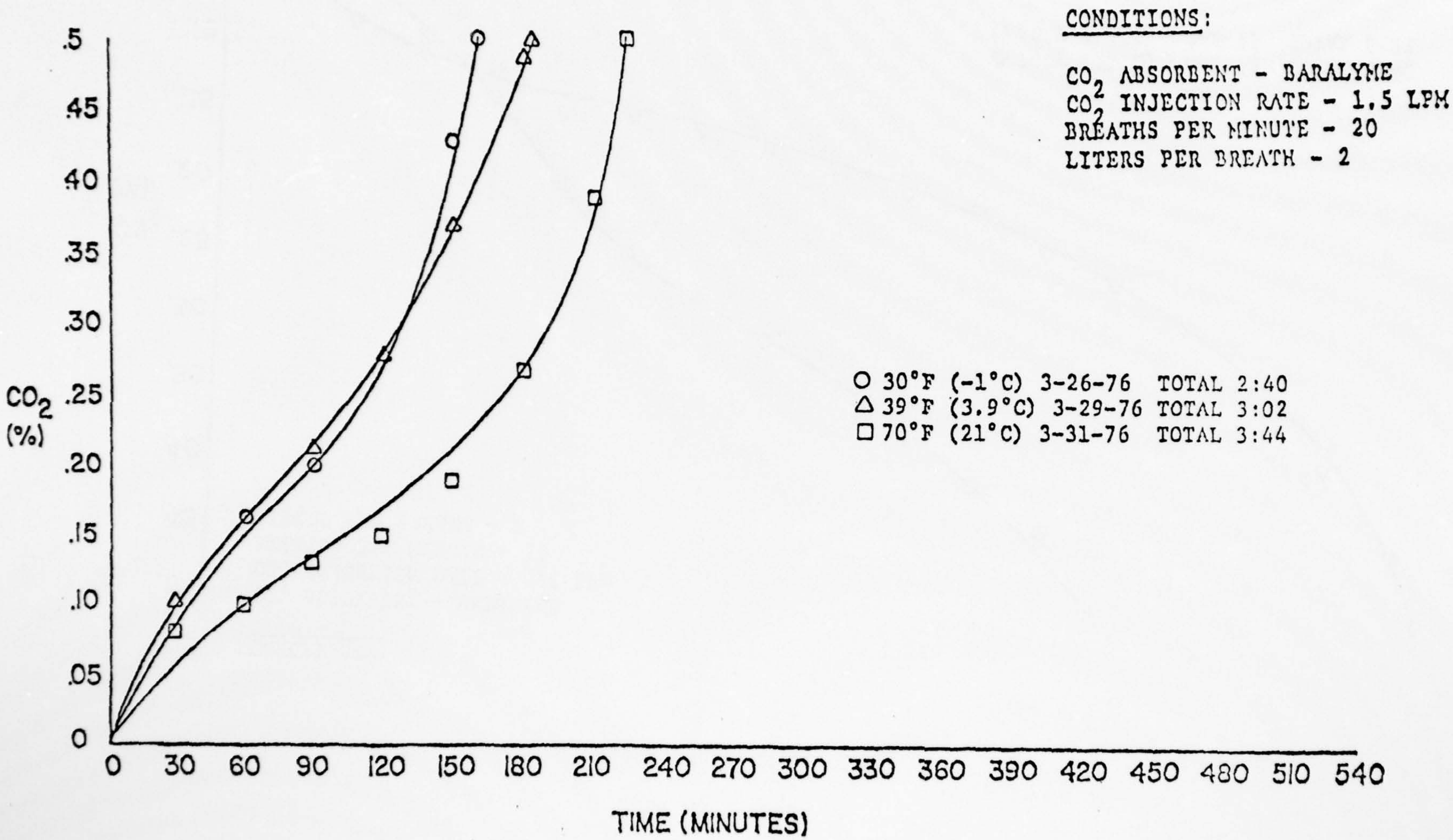


FIGURE 9

SLSS MK 1 SCUBA

SCRUBBER DURATION STUDIES

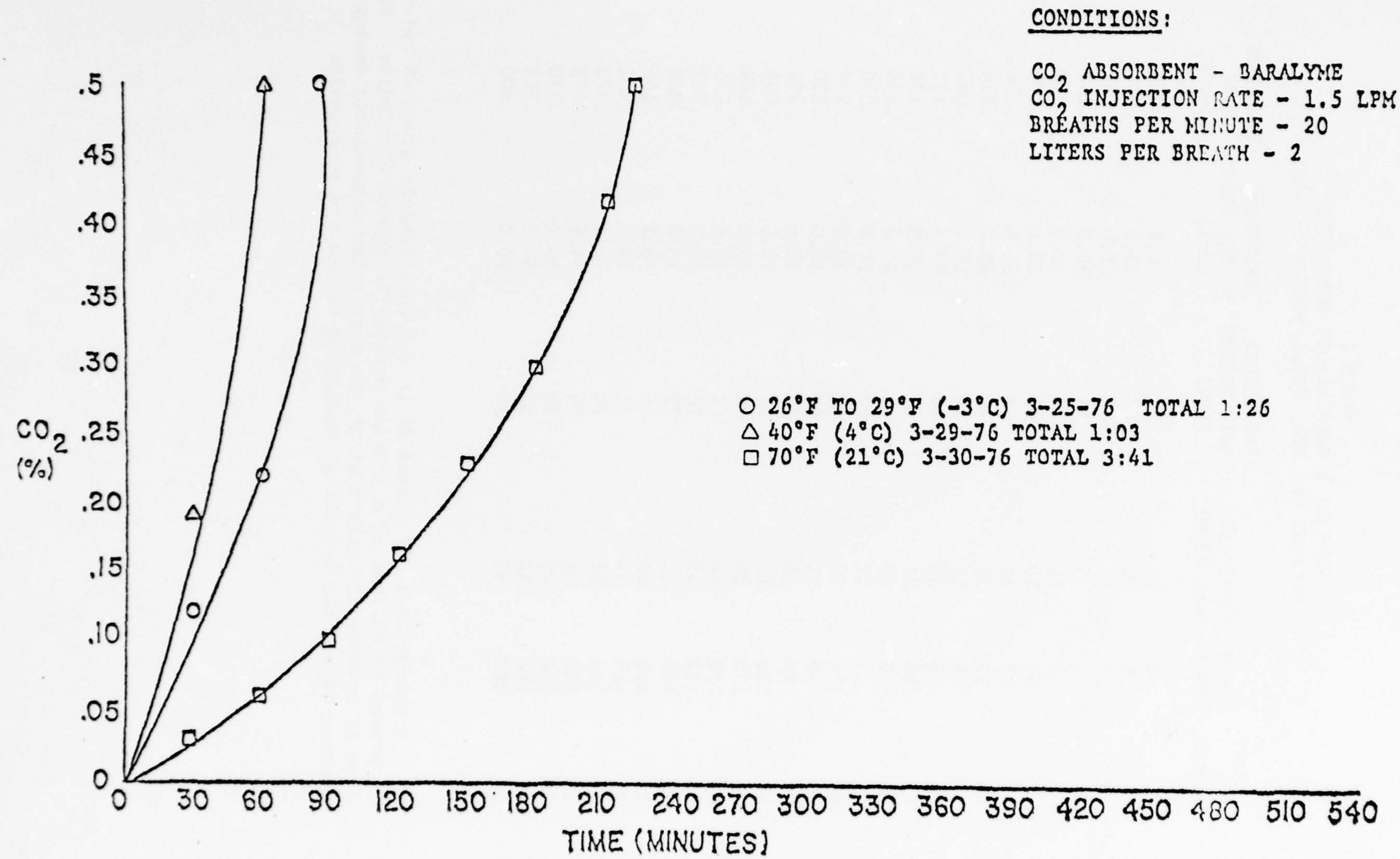


FIGURE 10

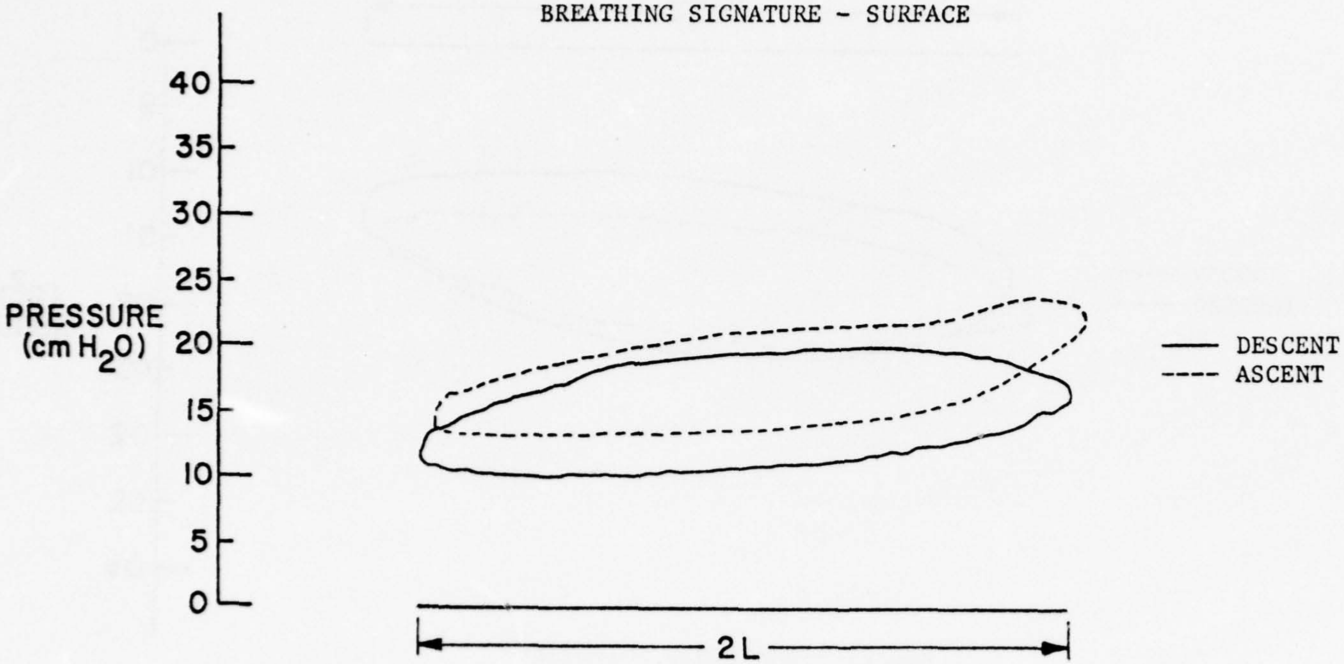
TABLE 1
SLSS MK 1 RESPIRATORY WORK STUDY
DILUENT GAS AIR, TIDAL VOLUME (2 LPB)

RUN NUMBER	DEPTH (FSW)	BREATHING RATE (BPM)	RESPIRATORY MINUTE VOLUME (LPM)	PRESSURE VOLUME AREA (Cm^2)	BREATHING WORK ($Kg\text{-}m/\ell$)	Δ P ($Cm\ H_2O$)
1	0	11	22	6.9	.035	6
2	0	20	40	13.3	.062	10
3	0	31	62	25.0	.125	18
4	0	35	70	30.0	.150	21
5	33	11	22	10.0	.050	7
6	33	20	40	20.0	.100	13
7	33	31	62	34.8	.174	23
8	33	35	70	45.2	.226	32 *
9	66	11	22	10.2	.051	8
10	66	20	40	27.4	.137	19
11	66	31	62	35.6	.178	31 *
12	66	35	70	54.8	.274	36 *
13	99	11	22	14.0	.070	9
14	99	20	40	30.0	.150	20
15	99	31	62	46.0	.230	32 *
16	99	35	70	58.8	.294	42 *
17	132	11	22	12.8	.064	9
18	132	20	40	28.2	.141	19
19	132	31	62	52.9	.265	36 *
20	132	35	70	65.5	.327	46 *
21	165	11	22	13.8	.069	10
22	165	20	40	33.2	.166	22
23	165	31	62	56.3	.282	40 *
24	165	35	70	74.6	.373	53 *
25	200	11	22	14.6	.073	10
26	200	20	40	34.0	.170	25
27	200	31	62	63.8	.319	45 *
28	200	35	70	80.0	.400	57 *

* Although these ΔP exceed 30 $Cm\ H_2O$ requirements given in reference (a), it proved to be less of a problem during the manned ΔP studies. Manned dive ΔP studies indicate that at the work rates encountered during normal working dives, the breathing resistance values are acceptable.

SLSS MK 1 SCUBA

BREATHING SIGNATURE - SURFACE



CONDITIONS

DILUENT GAS - AIR
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

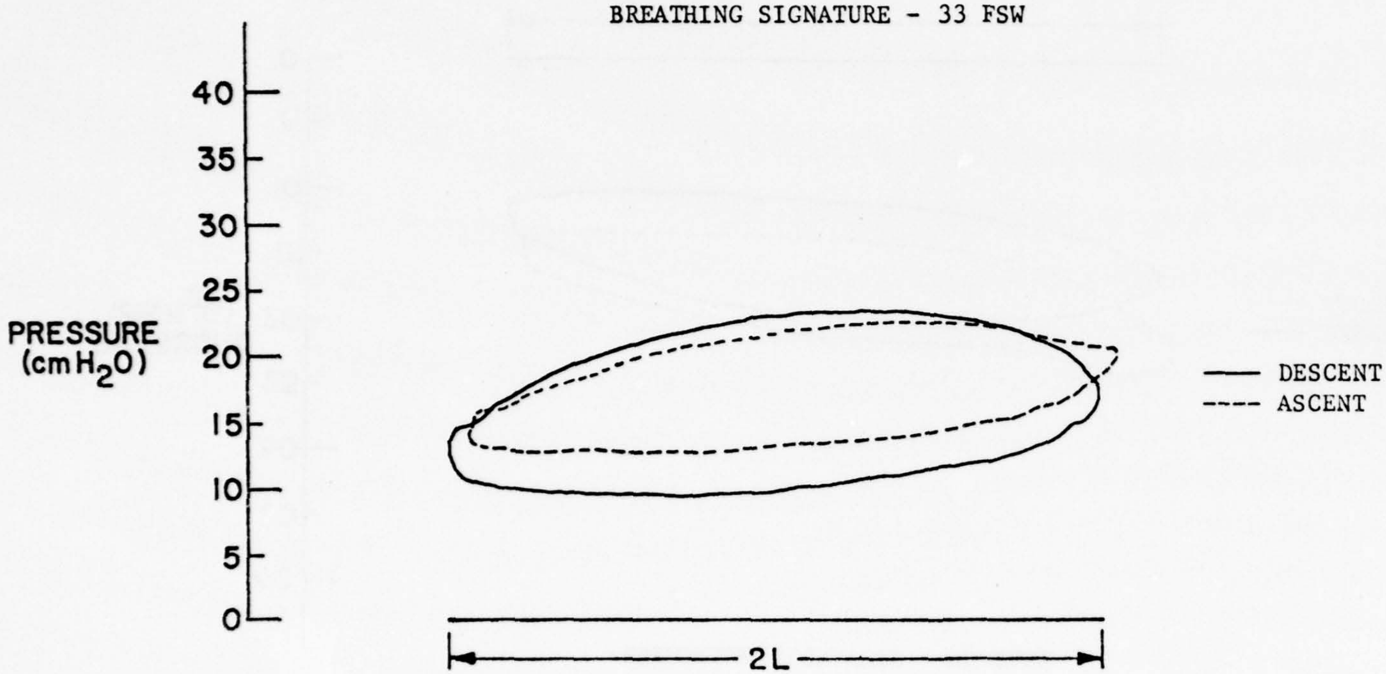
RESULTS

WORK, DESCENT (kg·m/l) - 0.062
PV AREA (cm^2)
DESCENT - 13.3
ASCENT - 12.1

FIGURE 11A

SLSS MK 1 SCUBA

BREATHING SIGNATURE - 33 FSW



CONDITIONS

DILUENT GAS - AIR
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

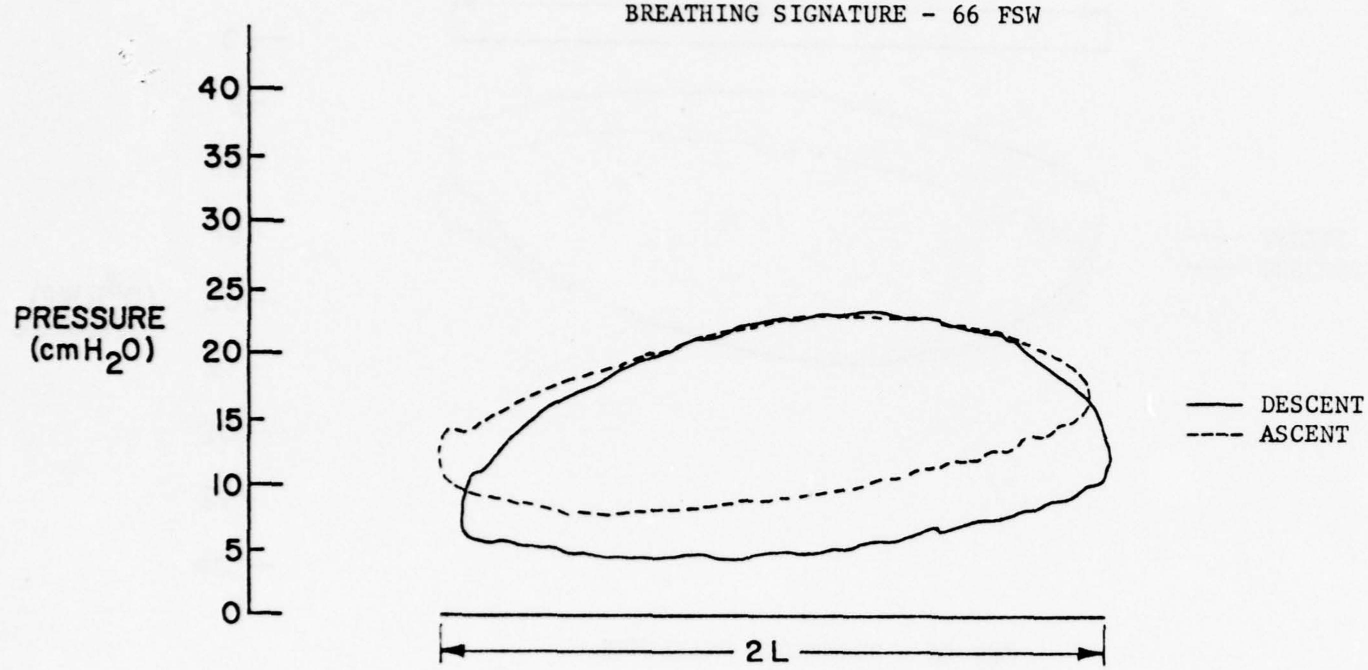
RESULTS

WORK, DESCENT (kg·m/l) - 0.100
PV AREA (cm^2)
DESCENT - 20.0
ASCENT - 13.3

FIGURE 11B

SLSS MK 1 SCUBA

BREATHING SIGNATURE - 66 FSW



CONDITIONS

DILUENT GAS - AIR
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

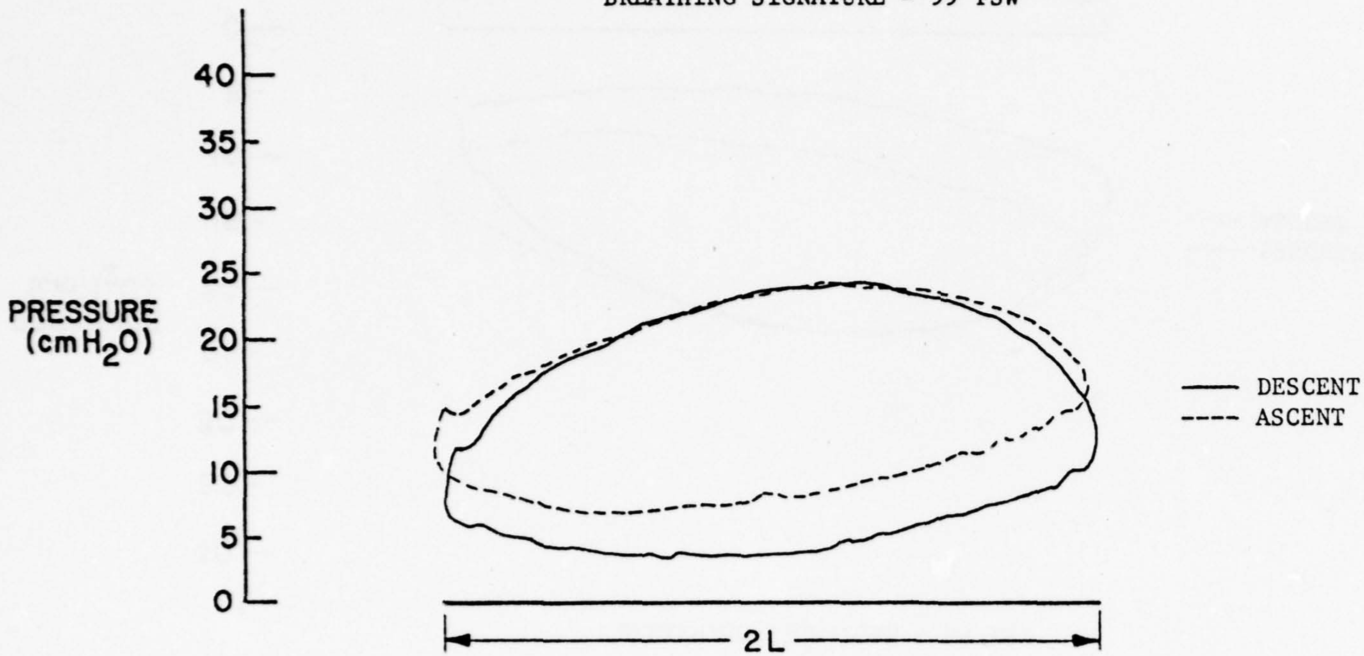
RESULTS

WORK, DESCENT (kg·m/l) - 0.137
PV AREA (cm^2)
DESCENT - 27.4
ASCENT - 20.4

FIGURE 11C

SLSS MK 1 SCUBA

BREATHING SIGNATURE - 99 FSW



CONDITIONS

DILUENT GAS - AIR
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

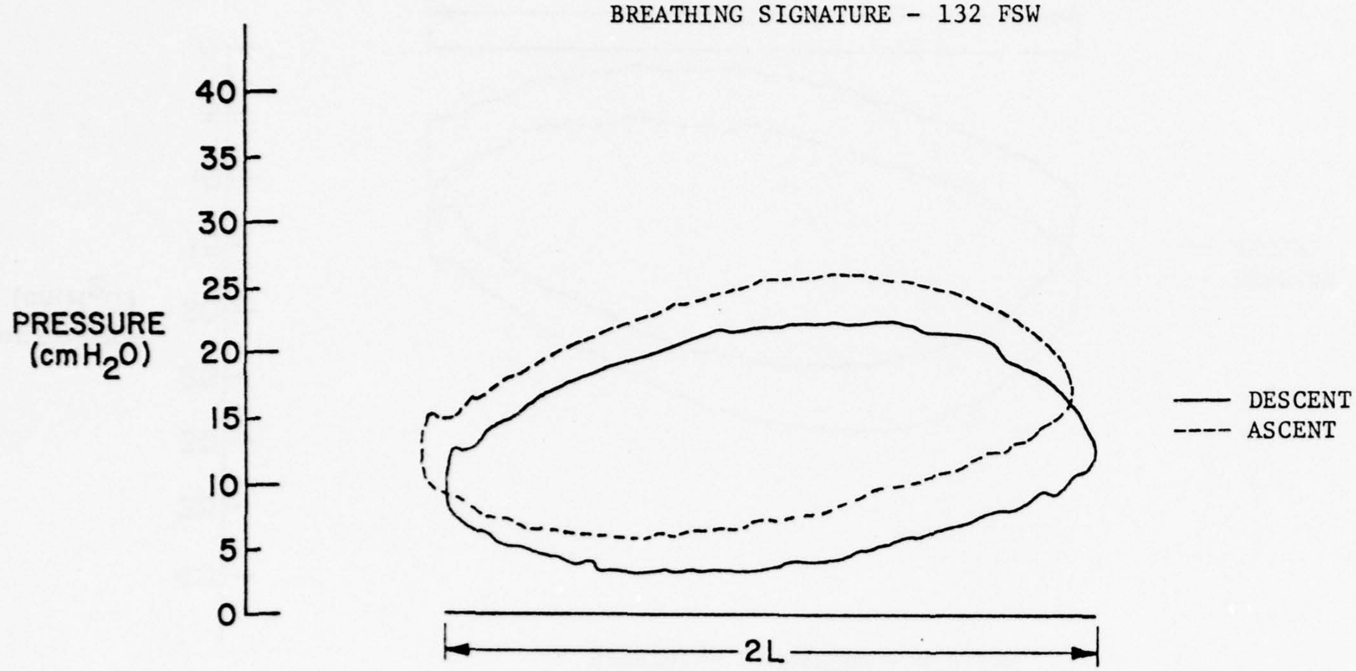
RESULTS

WORK, DESCENT (kg·m/l) - 0.150
PV AREA (cm^2)
DESCENT - 30.0
ASCENT - 22.0

FIGURE 11D

SLSS MK 1 SCUBA

BREATHING SIGNATURE - 132 FSW



CONDITIONS

DILUENT GAS - AIR
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

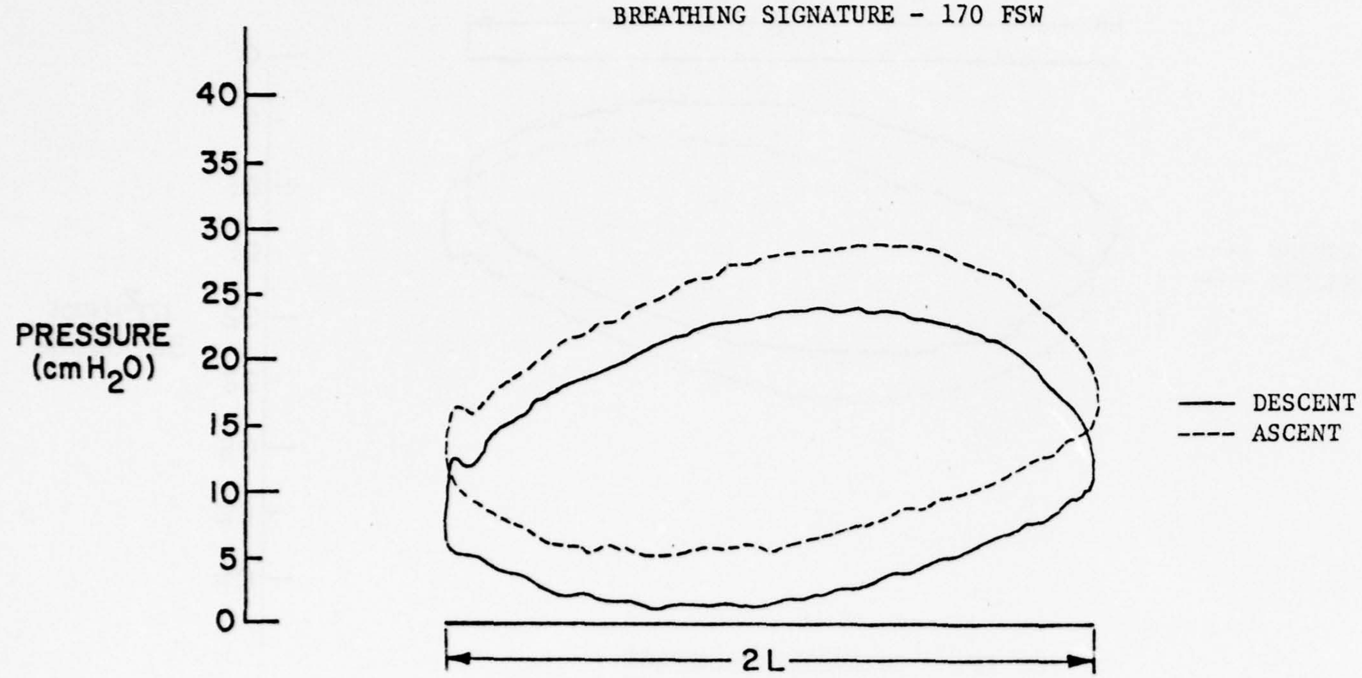
RESULTS

WORK, DESCENT (kg·m/l) - 0.141
PV AREA (cm^2)
DESCENT - 28.2
ASCENT - 22.0

FIGURE 11E

SLSS MK 1 SCUBA

BREATHING SIGNATURE - 170 FSW



CONDITIONS

DILUENT GAS - AIR
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

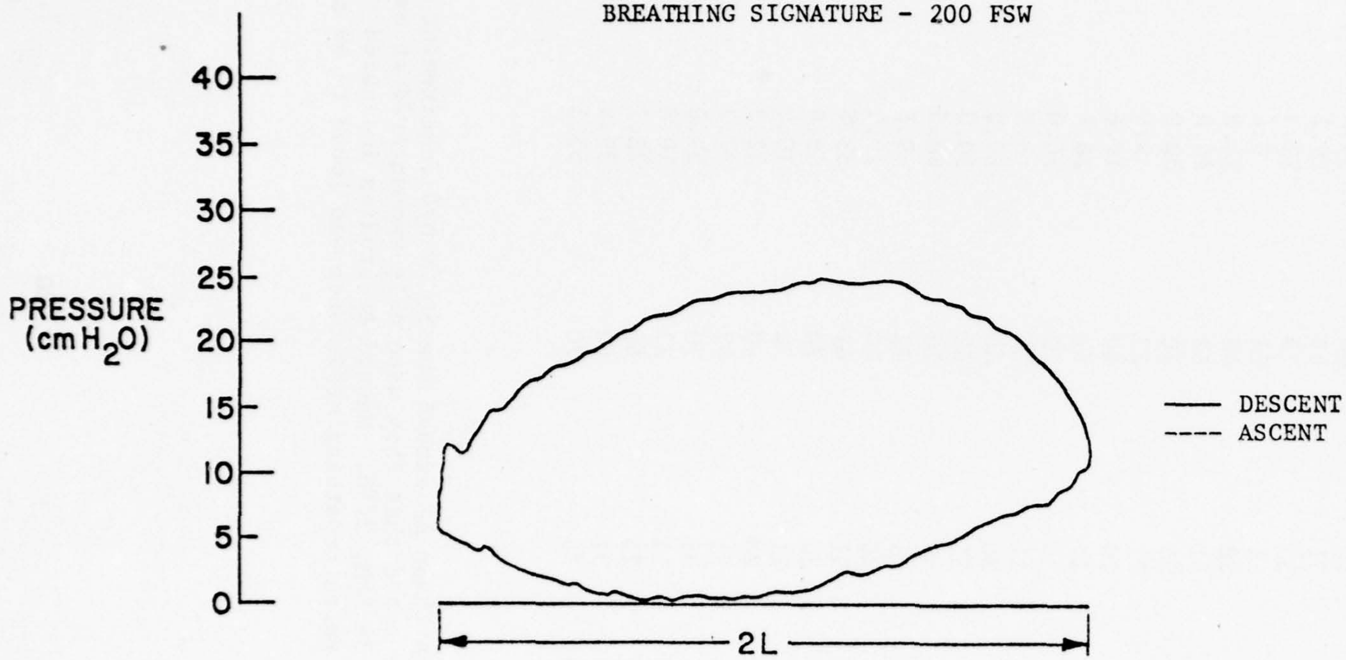
RESULTS

WORK, DESCENT (kg·m/l) - 0.166
PV AREA (cm^2)
DESCENT - 33.2
ASCENT - 33.2

FIGURE 11F

SLSS MK 1 SCUBA

BREATHING SIGNATURE - 200 FSW



CONDITIONS

DILUENT GAS - AIR
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

RESULTS

WORK, DESCENT (kg·m/l) - 0.17
PV AREA (cm^2)
ASCENT - 34.0

FIGURE 11G

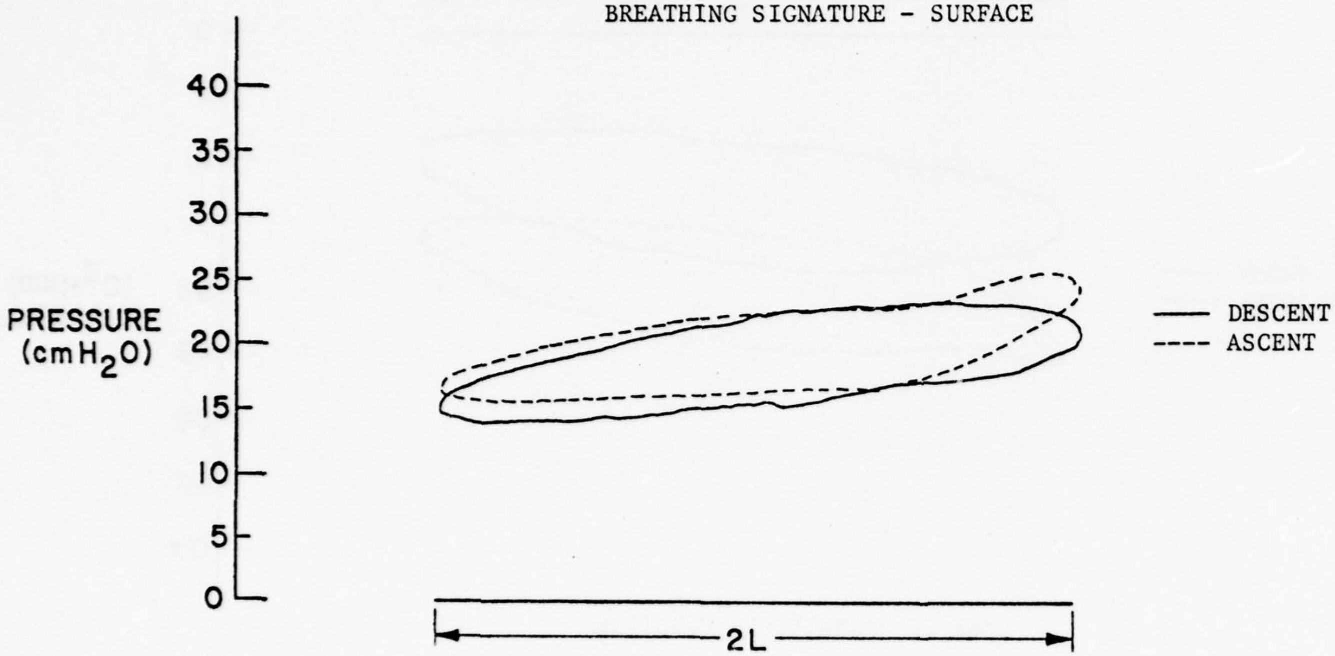
TABLE 2
SLSS MK 1 RESPIRATORY WORK STUDY
DILUENT GAS HeO_2, TIDAL VOLUME (2 LPB)

RUN NUMBER	DEPTH (FSW)	BREATHING RATE (BPM)	RESPIRATORY MINUTE VOLUME (LPM)	PRESSURE VOLUME AREA (Cm^2)	BREATHING WORK (Kg-m/ℓ)	Δ P ($Cm\ H_2O$)
1	0	11	22	5.5	.027	6
2	0	20	40	10.8	.054	9
3	0	31	62	19.1	.091	15
4	0	35	70	22.3	.112	17
5	33	11	22	8.4	.042	8
6	33	20	40	14.8	.074	11
7	33	31	62	24.8	.124	16
8	33	35	70	32.0	.160	22
9	66	11	22	9.0	.045	8
10	66	20	40	16.6	.083	13
11	66	31	62	26.4	.132	18
12	66	35	70	36.0	.180	25
13	99	11	22	8.8	.044	8
14	99	20	40	18.2	.091	13
15	99	31	62	30.8	.154	21
16	99	35	70	40.2	.206	28
17	132	11	22	9.8	.049	8
18	132	20	40	19.1	.096	14
19	132	31	62	33.8	.169	23
20	132	35	70	46.0	.230	32 *
21	165	11	22	10.0	.050	8
22	165	20	40	22.7	.113	15
23	165	31	62	37.3	.186	26
24	165	35	70	51.0	.255	36 *
25	200	11	22	10.8	.054	9
26	200	20	40	23.1	.116	16
27	200	31	62	39.9	.199	28
28	200	35	70	55.5	.278	39 *

* Although these ΔP exceed the 30 $Cm\ H_2O$ requirement given in reference (*e*) it should be noted that they were only encountered at extremely heavy work rates, i.e. 35 BPM, $2\ell PB$. Manned ΔP studies indicated that under normal diving work rates breathing resistance was found to be acceptable.

SLSS MK 1 SCUBA

BREATHING SIGNATURE - SURFACE



CONDITIONS

DILUENT GAS - HeO_2 (80/20)
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

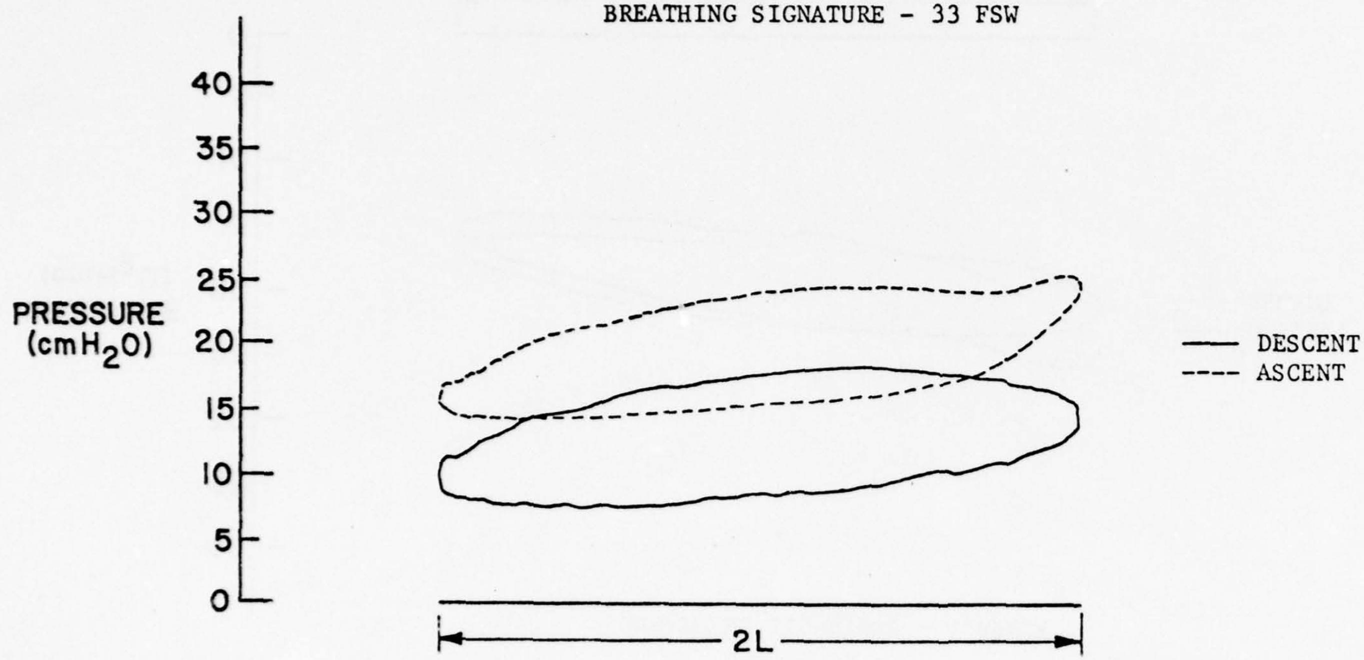
RESULTS

WORK, DESCENT (kg·m/l) - 0.054
PV AREA (cm^2)
DESCENT - 10.8
ASCENT - 10.2

FIGURE 12A

SLSS MK 1 SCUBA

BREATHING SIGNATURE - 33 FSW



CONDITIONS

DILUENT GAS - HeO_2 (80/20)
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

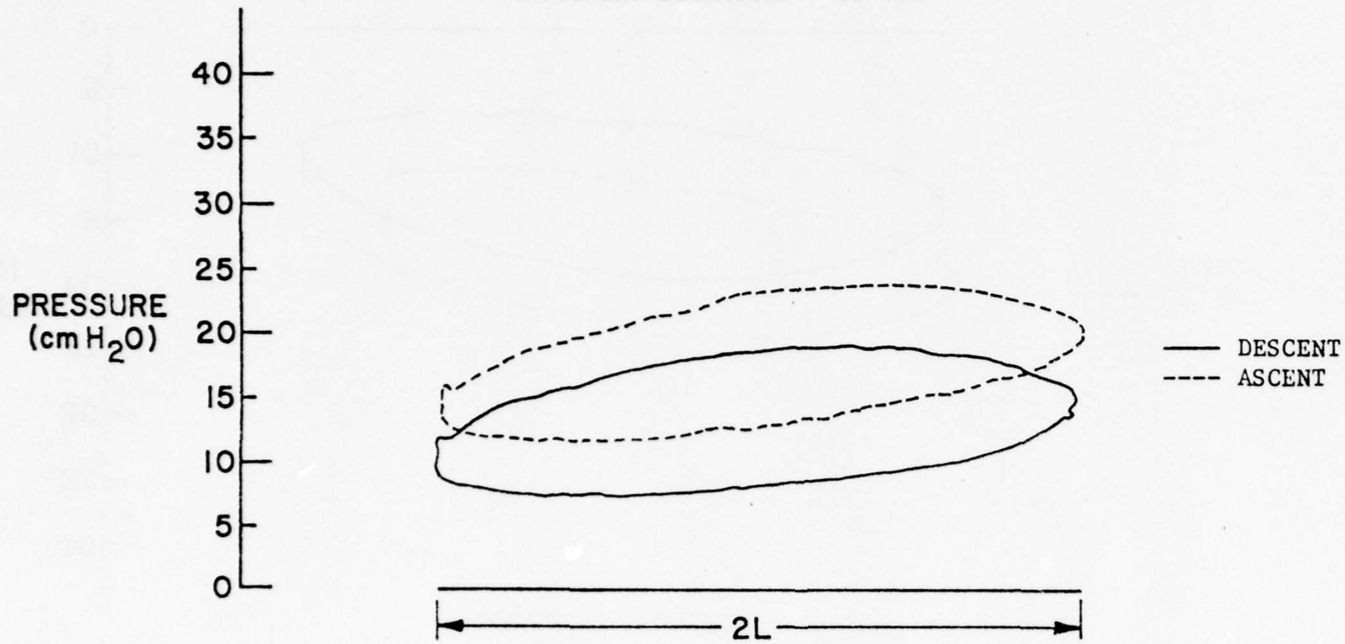
RESULTS

WORK, DESCENT (kg·m/l) - 0.074
PV AREA (cm^2)
DESCENT - 14.8
ASCENT - 13.5

FIGURE 12B

SLSS MK 1 SCUBA

BREATHING SIGNATURE - 66 FSW



CONDITIONS

DILUENT GAS - HeO_2 (80/20)
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

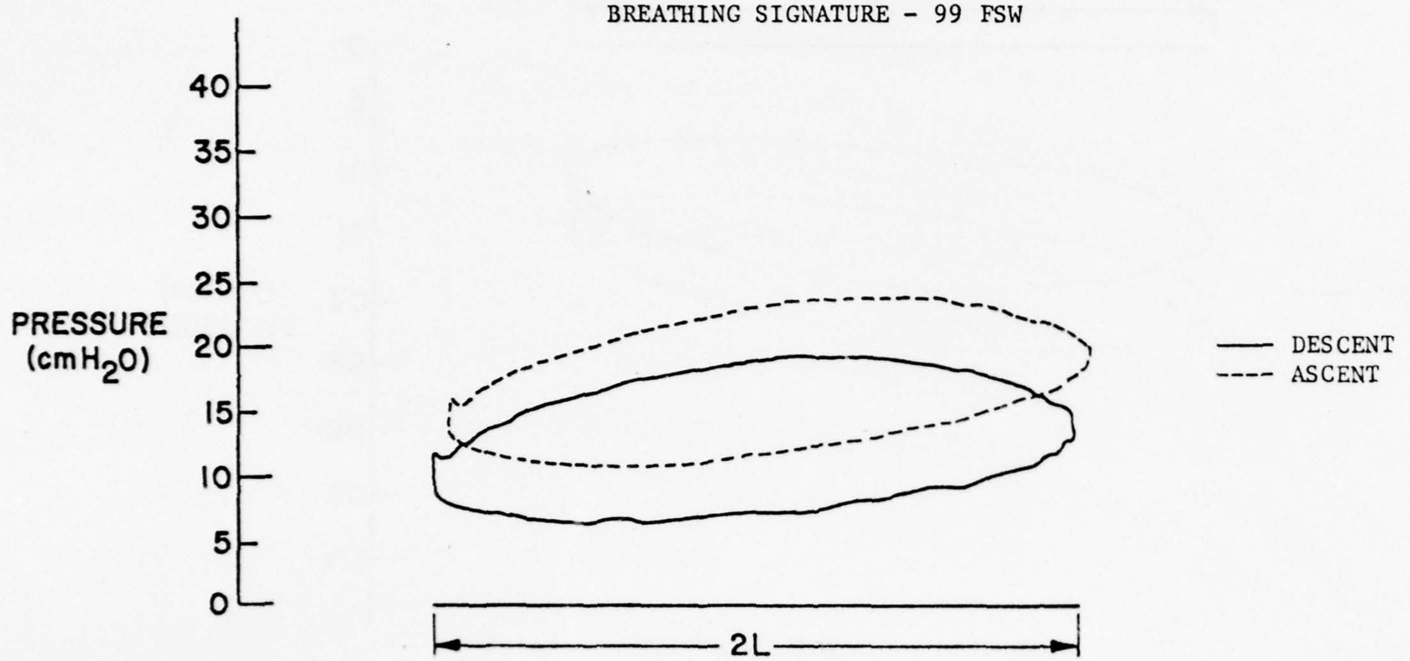
RESULTS

WORK, DESCENT (kg·m/l) - 0.083
PV AREA (cm^2)
DESCENT - 16.6
ASCENT - 15.0

FIGURE 12C

SLSS MK 1 SCUBA

BREATHING SIGNATURE - 99 FSW



CONDITIONS

DILUENT GAS - HeO_2 (80/20)
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

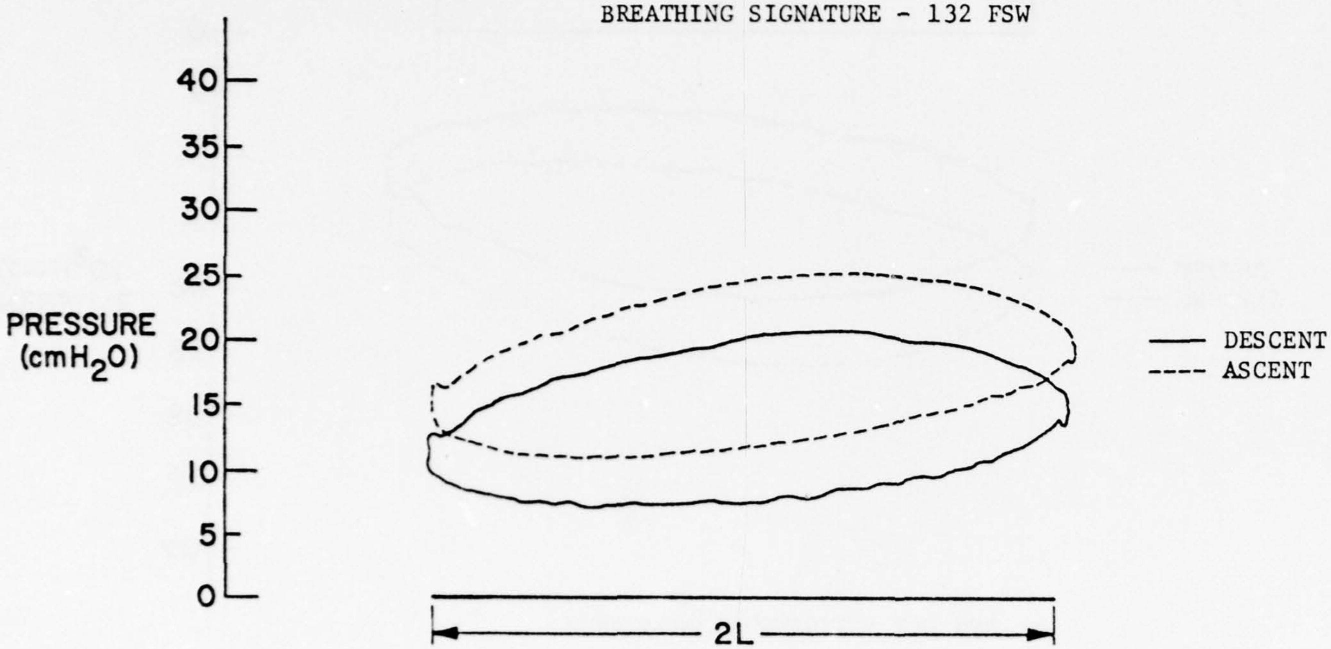
RESULTS

WORK, DESCENT (kg·m/l) -0.091
PV AREA (cm^2)
DESCENT - 18.2
ASCENT - 17.3

FIGURE 12D

SLSS MK 1 SCUBA

BREATHING SIGNATURE - 132 FSW



CONDITIONS

DILUENT GAS - HeO_2 (80/20)
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

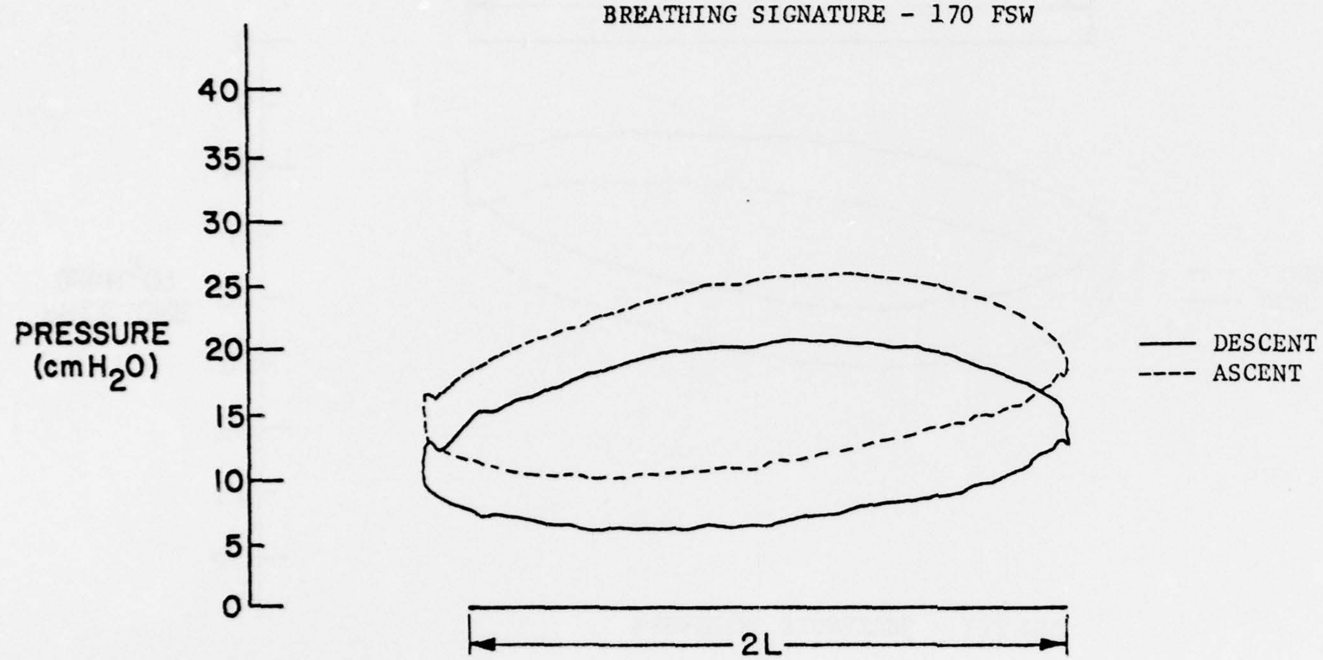
RESULTS

WORK, DESCENT (kg.m/l) - 0.096
PV AREA (cm^2)
DESCENT - 19.1
ASCENT - 19.8

FIGURE 12E

SLSS MK 1 SCUBA

BREATHING SIGNATURE - 170 FSW



CONDITIONS

DILUENT GAS - HeO_2 (80/20)
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

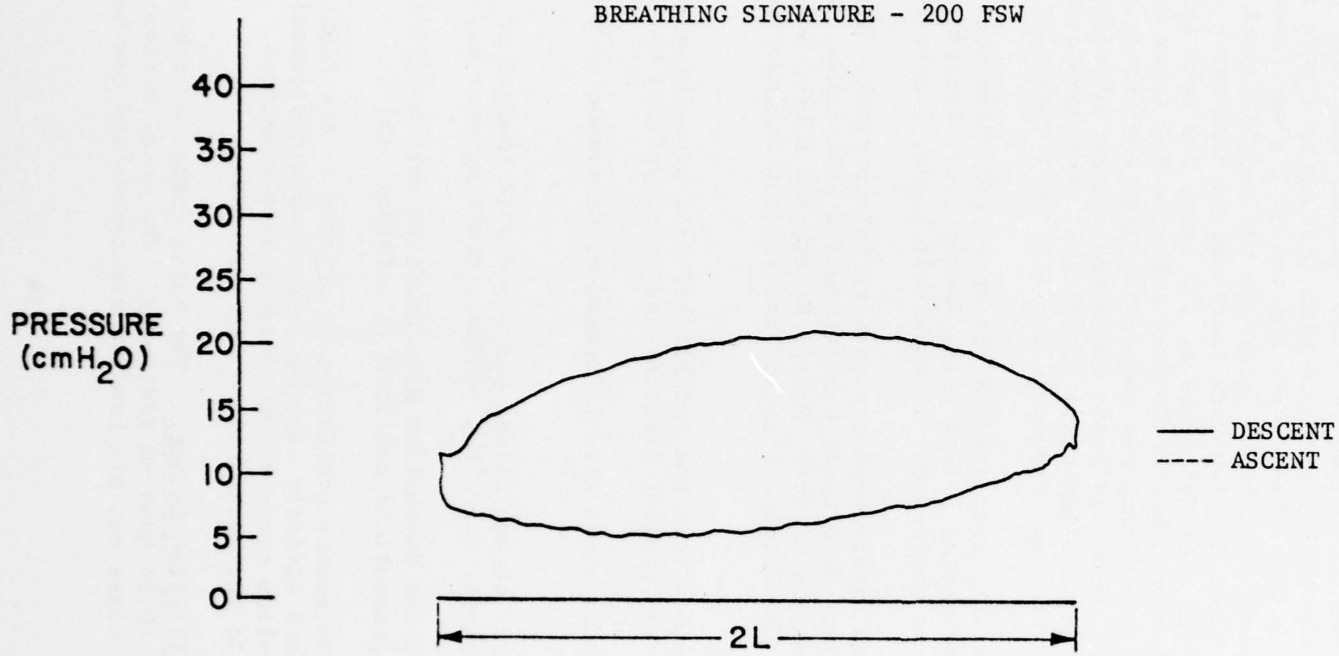
RESULTS

WORK, DESCENT (kg.m/l) - 0.113
PV AREA (cm^2)
DESCENT - 22.7
ASCENT - 21.8

FIGURE 12F

SLSS MK 1 SCUBA

BREATHING SIGNATURE - 200 FSW



CONDITIONS

DILUENT GAS - HeO_2 (80/20)
BREATHING RATE - 20 BPM
TIDAL VOLUME - 2 LPB

RESULTS

WORK, DESCENT (kg·m/l) - 0.118
PV AREA (cm^2)
DESCENT - 23.1

FIGURE 12G

Section 3

MANNED TESTING

3.1 General. The manned testing of the SLSS MK 1 was undertaken in three distinct phases - training, a saturation dive, and open sea dives.

3.1.1 Training consisted of classroom sessions followed by pool training until it was determined that the test personnel had adequate knowledge of the MK 1 to proceed with testing in a safe manner. A saturation dive with five divers and two MK 1's was conducted to gather physiological data to determine the capability of the MK 1 to support life under varying work loads and in cold water (40°F, 4°C). The dive profile included dives at 130 feet, 200 feet and 225 feet. Baseline data were taken at 20 feet prior to the start of the dive. The data obtained during the saturation dive are shown in Tables 3A, 3B, 4A and 4B. Open sea tests consisted, first, of additional training to increase the test personnel population, then completion of the dives prescribed in the Test Procedure for SLSS MK 1 Technical Evaluation.

3.1.2 The initial training and the saturation dive were conducted at the Navy Experimental Diving Unit, Panama City, Florida. The balance of TECHEVAL was carried out at Roosevelt Roads, Puerto Rico.

3.1.3 Sixteen divers were assigned to this project. They were drawn from operational Underwater Demolition and SEAL teams. NAVSPECWARGRU 2 provided a Project Officer, Master Diver, and a Deep Sea Medical Technician. The Project Director and Project Engineer were assigned from NEDU.

3.1.4 Variations from the established test procedures were made at the direction of the project director and were typified by the following:

a. Bottom times were increased or decreased as weather or task dictated.

b. Types of evolutions performed were changed or rescheduled as support equipment, i.e. SDV, SUBTRAP, training devices, became available.

c. Extreme depth/time dive profiles were modified to be congruent with safety precautions outlined in reference (a).

d. Maintenance procedures as written in the SLSS MK 1 Technical Manual were not strictly adhered to as it was discovered that they did not always follow accepted Navy maintenance practices. In such cases, corrections to the Technical Manual were made.

3.2 Data Collection Summary. The total number of dives made during TECHEVAL was three hundred sixty-one. The total bottom time accumulated during these dives was six hundred ninety-six and one half hours.

3.3 Operational and Technical Characteristics. The required Operational and Technical characteristics, together with the results achieved during TECHEVAL, are shown in Table 3.

3.4 Comments on Data Analysis. The values arrived at for the various technical characteristics are based on the use of ten test units with an accumulated bottom time of 696.5 hours. The usage time, number of dives and maintenance actions for individual units are outlined in Table 4. It will be seen that units one through eight accumulated considerably more use than units nine and ten. This was because two units (#9 and #10) were kept in a standby condition. The purpose was that, in the event of a malfunction of any of the eight primary test units during pre-dive procedures, one of the standby units would be pre-dived and dived in that day's evolution. This procedure permitted each evolution to have eight test units participating and allowed commencement of operations early in the day. The malfunctioned unit would then be fault-located and repaired to allow use on the next evolution. Additionally, the standby units were utilized for demonstration and training for additional project personnel arriving on board.

3.5 Discussion of Aborts. One critical abort was experienced when a canister cover seal was accidentally crimped between the canister cover and canister housing. The diver, upon entering the water was aware of a gurgling sound in his unit and immediately surfaced. The SLSS MK 1 was immediately opened and the water that had entered was totally absorbed by the moisture absorbers with no water having entered the canister. A number of aborts were experienced when the O_2 bottle manifold O-ring failed. This problem was completely solved by changing to a standard K-valve (the same as on the diluent bottle). An additional several hundred hours of dive time with this modification proved to be problem-free, thereby proving the validity of the solution to this problem.

3.6 Divers Comments and Recommendations

1. Did you encounter any problems during the pre-dive procedure?
   Response: 100% No

2. Did you encounter any problems during post-dive procedure?
   Response: 100% No

3. Were there any breathing problems encountered during the dives?
   Response: 38% No - 62% Yes

Comment: The periodic light breathing resistance experienced by the divers is caused by the inability of the original harness assembly to hold the SLSS MK 1 snugly to the diver's back and in the proper attitude on the

diver's back in relation to his 7th cervical vertibra. Testing with a modified harness assembly has eliminated this problem.

4. Were there any buoyancy or trim problems encountered during the dives?
Response: 100% Yes

Comment: The unit is 1.5 lbs (.68 Kg) positive in salt water with the diaphragm half full and the oxygen and diluent bottles half full. The center of buoyancy of the unit is located at the diaphragm. This condition creates a trim moment which tends to pull the diver up causing a trim problem. The addition of internal trim weight to the upper portion of the unit, making it neutrally buoyant in salt water, eliminates this problem.

3.6.1 Recommended Modifications. Divers were asked to list any general comments or recommendations concerning the SLSS MK 1. A representative sampling, with comments by the Project Director, are listed below.

a. A voltage curve be put in the O & M Manual giving voltage vs. time remaining.
Comment: This will be incorporated into the manual prior to distribution.

b. Install a Bendix-type cable connector vice hardwire on primary read out cable to electronic module.
Comment: This is possible but Bendix does not make an eight-pin connector for this cable size. Another type that is equal to the Bendix type will be incorporated.

c. Secondary display trim pots adjustment screws should be made out of a more gall-resistant material.
Comment: Alternate screws are being investigated.

d. Secondary display lens is too easily scratched.
Comment: The possibility of recessing the lens below the surface of its retainer case is being investigated.

e. Stainless steel-sheathed LP hose from regulator to tubing connection causes chafing of the primary display cable when diluent bottle is installed.
Comment: Investigations are being made into a replacement hose.

f. Install an in-line filter on diluent side as on the oxygen side to prevent small particulate matter from blocking the diluent add valve.
Comment: Recommend a filter be added to the diluent side.

g. Replace oxygen resuscitator fitting on oxygen flask with standard K-valve to prevent O-ring failures.
Comment: The resuscitation type fitting and O-ring are not designed to work with 3000 psi. Recommend changing to a standard K-valve.

h. Put scribe marks on canister housing to insure proper positioning of diaphragm and scrubber cover seal.
Comment: Recommend this be done to insure proper positioning of diaphragm and cover seal during installation.

i. MK 1 should be neutrally buoyant in salt water with the diaphragm and bottles half full.
Comment: Recommend this be achieved by adding trim weights internally at the top of the unit.

j. Color Code bottles.
Comment: Recommend this be done in accordance with MIL STD 101B.

k. Change to washable and reusable moisture absorbers.
Comment: Recommend this be done to lower the cost per dive by $7.00. Reusing moisture absorbers without washing could cause a dangerous bacteria growth problem.

l. Place a warning stripe around canister and canister cover to insure seals are in place properly.
Comment: Recommend this be done.

m. Place quick-disconnect type connectors on sensor leads to facilitate the removal of sensors for storage.
Comment: Recommend a banana type connector be used. If units are not to be dived on a continual basis, the sensors should be stored in an inert environment to prolong life.

n. Change electronics module battery lead so that replacement does not require the removal or opening of the electronics module.
Comment: Recommend use of a water-and pressure-proof quick disconnect for the battery lead in the battery compartment.

o. All metal parts should be made of a corrosion-resistant material.
Comment: Recommend that, where possible, metal parts be made of 316 stainless material.

p. Helicoils in the secondary display and the electronic module tend to back out if screws are over-tightened.
Comment: Recommend Keenserts or equivalent fitting be used to eliminate this problem.

q. Modify bypass valves so as to better distinguish between the two with gloved hands.
Comment: Recommend the addition of an "O" shape to the oxygen by-pass valve lever and a cone shape to the diluent valve lever to eliminate this problem.

r. Secondary attaching clip tends to bend out of shape.
Comment: Recommend change to some type of snap link or adequate spring steel material.

s. Oxygen and diluent bottles rust.
Comment: Recommend changing to Inconel bottles.

t. Illuminate the secondary display.
Comment: Investigate the availability of non-radioactive, light-absorbing coatings or the use of fiber optics.

u. Change harness assembly to a type that better holds the unit in the proper position on the diver's back.
Comment: Recommend changing to prototype harness developed by NEDU or harness developed by NATICK.

v. Shift bottle pressure gauges to secondary read out.
Comment: Recommend this be done by means of pressure transducers being added to the unit with the pressures displayed on the secondary display meter.

w. Primary display is too bright for night clandestine operations.
Comment: Utilize an elongated Velcro wrist strap or a snap-on cover that would enable diver to read the display but preclude observation from the surface.

TABLE 3A

SLSS MK 1 MANNED RESPIRATORY WORK ON VERTICAL ERGOMETER

DILUENT GAS AIR

DEPTH (FSW)	WORK MEASUREMENT (KG - M / SEC.)	HIGH LOW O_2 AS SEEN BY SENSORS (%)	Δ P ($CM\ H_2O$)	CO_2 INHALATION (mm-Hg) ***	HEART RATE BEATS PER MINUTE	BREATHING RATE (BPM)
20	2.5	.56/.65	13	2.13	111	21
20	5.0	.60/.66	16	2.28	129	26
20	7.5	.60/.68	22	2.89	141	20
20	10.0	.59/.67	26	3.04	159	26
20	12.5	**	**	**	**	**
130	2.5	.67/.83	24	*	108	17
130	5.0	.74/.82	30	0.49	126	21
130	7.5	.68/.79	36	1.58	138	24
130	10.0	.67/.73	40	2.21	141	29
200	2.5	.75/.83	14	1.13	84	*
200	5.0	.73/.87	48	3.17	123	*
200	7.5	.71/.85	54	4.35 ****	138	*
200	10.0	.71/.87	64	6.39 ****	162	*

* Denotes lack of data resulting from temporary test monitoring equipment failure.

** Denotes cut off at this point diver reached his maximum work level.

*** 3.8mm-Hg CO_2 equal to .5% CO_2.

**** Although this exceeds the value 3.8mm-Hg CO_2 the entire dive was under the direct supervision of a diving medical officer. The respiratory rates indicated no requirement to terminate the dive.

TABLE 3B
SLSS MK 1 MANNED RESPIRATORY WORK ON HORIZONTAL ERGOMETER
DILUENT GAS AIR

DEPTH (FSW)	WORK MEASUREMENT (KG - M/SEC.)	HIGH LOW O_2 AS SEEN BY SENSORS (%)	Δ P (CM H_2O)	CO_2 INHALATION (mm-Hg) ***	HEART RATE BEATS PER MINUTE	BREATHING RATE (BPM)
20	2.5	.58/.66	8	1.96	114	23
20	5.0	.59/.70	24	2.05	117	19
20	7.5	.56/.65	25	1.95	129	21
20	10.0	.55/.65	32	2.20	150	27
20	12.5	.58/.66	46	2.96	180	34
30	2.5	.69/.84	20	0.45	96	16
30	5.0	.77/.82	22	0.40	93	20
30	7.5	.71/.75	30	1.13	93	18
130	10.0	.70/.83	30	1.16	97	20
130	12.5	**	**	**	**	**
200	REST	.76/.78	8	*	60	15
200	2.5	.71/.96	30	*	96	16
200	5.0	.71/.79	36	*	99	15
200	7.5	.71/.90	36	*	110	18
200	10.0	*	60	*	120	20

* Denotes lack of data resulting from temporary test monitoring equipment failure.

** Denotes cut off at this point diver reached his maximum work level.

*** 3.8mm-Hg CO_2 equal to .5% CO_2.

TABLE 4A
SLSS MK 1 MANNED RESPIRATORY WORK ON VERTICAL ERGOMETER
DILUENT GAS HeO_2

DEPTH (FSW)	WORK MEASUREMENT (KG - M/SEC.)	HIGH LOW O_2 AS SEEN BY SENSORS (%)	Δ P (CM H_2O)	CO_2 INHALATION (mm-Hg) ***	HEART RATE BEATS PER MINUTE	BREATHING RATE (BPM)
200	2.5	.67/.73	8	0.00	93	*
200	5.0	.67/.73	24	0.00	90	15
200	7.5	.59/.77	26	1.34	130	16
200	10.0	.68/.79	32	5.15 ****	153	20
225	REST	.77/.99	10	0.00	93	14
225	2.5	.77/.91	12	0.00	120	19
225	5.0	.73/.91	21	0.00	132	33
225	7.5	.76/.85	24	0.00	150	24
225	10.0	.77/.84	28	0.71	168	26

* Denotes lack of test data resulting from temporary malfunction of monitoring equipment.

** Denotes cut off at this point diver reached his maximum work level.

*** 3.8mm-Hg CO_2 equal to .5% CO_2.

**** Although this exceeds the value 3.8mm-Hg CO_2 the entire dive was under the direct supervision of a diving medical officer. The respiratory rates indicated no requirement to terminate the dive.

TABLE 4B
SLSS MK 1 MANNED RESPIRATORY WORK ON HORIZONTAL ERGOMETER
DILUENT GAS HeO_2

DEPTH (FSW)	WORK MEASUREMENT (KG - M / SEC.)	HIGH LOW O_2 AS SEEN BY SENSORS (%)	Δ P (CM H_2O)	CO_2 INHALATION (mm-Hg) ***	HEART RATE BEATS PER MINUTE	BREATHING RATE (BPM)
200	REST	.73/.76	*	0.00	84	*
200	2.5	.65/.78	10	0.00	96	14
200	5.0	.69/.90	26	1.50	99	15
200	7.5	.71/.88	28	3.65	114	16
200	10.0	.66/.82	32	5.69 ****	132	17
200	12.5	.69/.83	46	8.64 ****	153	19
200	15.0	.68/.82	50	1.23	160	24
200	17.5	**	**			
225	REST	*	23	0.00	99	12
225	2.5	.73/.87	24	0.00	87	7
225	5.0	.73/.88	22	0.77	99	10
225	7.5	.68/.94	26	0.00	111	11
225	10.0	.73/.82	30	0.71	126	12
225	12.5	.71/.88	40	0.59	141	11

* Denotes lack of test data resulting from temporary malfunction of monitoring equipment.

** Denotes cut off at this point diver reached his maximum work level.

*** 3.8mm-Hg CO_2 equal to .5% CO_2.

**** Although this exceeds the value 3.8mm-Hg CO_2 the entire dive was under the direct supervision of a diving medical officer. The respiratory rates indicated no requirements to terminate the dive.

Section 4

RELIABILITY TESTING

4.1 General. This test series was conducted in conjunction with the unmanned and manned tests. The series was designed to demonstrate that the SLSS MK 1 could operate in a reliable manner through a large number of dives in an extended and sustained diving evolution.

4.1.1 Location. This series of dives was conducted at the Navy Experimental Diving Unit, Panama City, Florida and Roosevelt Roads, Puerto Rico.

4.1.2 Personnel. Individuals from various Naval Special Warfare units and NEDU SLSS MK 1 project personnel performed the required dives.

4.2 Scope of Testing

4.2.1 Conduct. This series was conducted in accordance with TEMP-098-1.

4.2.2 Specific Test. A total of 311 dives were scheduled for this period. Dives were performed in both the unmanned and manned operating modes. Dives were up to 6 hours in duration; both day and night dives were conducted.

4.3 Results

4.3.1 Operations. A total of 361 dives were completed during this series with one abort recorded.

4.3.2 Maintenance. Pre-dive, post-dive, and turnaround checks as well as preventive maintenance procedures proved effective. There was little down-time for repairs and most material failures were discovered during pre-dive and post-dive checks. All failures were within first echelon maintenance capabilities.

4.4 Summary. The SLSS MK 1 has demonstrated an excellent capability for sustained diving operations with high reliability figures. It is felt that the incorporation of the recommended changes listed in 3.6.1 would further improve the reliability of the unit.

TABLE 5 TECHNICAL EVALUATION REQUIRED CRITERIA AND RESULTS

CRITERIA	REQUIRED	TECHEVAL RESULTS
RELIABILITY (1) Life Support (2) Mission	 0.97 at 95% conf. 0.95 at 80% conf.	 0.96 at 95% conf. .993 at 80% conf.
Compatibility	With full face mask or helmet	Full face mask not tested. Mask under development by NCSL and to be tested by NEDU in FEB 77. Helmet has not been developed for SPECWAR
Canister Life 29°F (-1.6°C) 40°F (4°C) 70°F (21°C)	 Test for best results 6 hrs. 6 hrs.	 2 hrs. 40 min. 7 hrs. 1.6 min. 8 hrs. 41 min.
Mobility	Diver when fully dressed, will be able to pass through a submarine hatch.	Demonstrated in dry mode but not in wet due to lack of submarine services.
Maximum Working Depth	Shall be capable of providing life support to a diver who is performing useful work to a depth of 200 ft. (61m)	Achieved.
Recirculator Duration 6 Hours	Provide life support at 200 FSW (61m) for the following conditions: A. For 15 min., the system must remove CO_2 at the rate of 1.5 LPM, using the equivalent of 20 BPM and a 2 LPB volume flow. For the next 5.5 hrs., it must remove CO_2 at a rate of .8 LPM, using 20 BPM and 2 LPB. The final 15 min. must be at a removal rate of 1.5 LPM using 20 BPM and 2 LPB.	Unit meets the requirements with the exception of the following: 1. 200 ft. open sea dive could not be conducted because of lack of PPO_2 decompression table - 130 ft. open sea testing was successfully completed utilizing the air equiv. tables and mission scenario.
6 Hours	B. For 30 min. the system must remove CO_2 at the rate of 1.5 LPM, using the equivalent of 20 BPM and a 2 LPB volume flow. For the next 5 hrs. the system is used. The final 30 min. must be at a removal rate of 1.5 LPM, using 20 BPM and 2 LPB.	

TABLE 5 (Cont'd)

CRITERIA	REQUIRED	TECHEVAL RESULTS
4.75 Hours	C. For 15 min. the system must remove CO_2 at 0.9 LPM using the equivalent of 17 BPM and 2 LPB volume flow. For the next 3 hrs. it must remove CO_2 at a rate of 0.8 LPM using the equivalent of 15 BPM and 2 LPB. For the last 1.5 hrs. it must remove CO_2 at the rate of 0.9 LPM using the equivalent of 17 BPM and 2 LPB.	
Bottle Pressure	Must be readable while operating	Achieved
Oxygen Partial Pressure Sensor	Redundent sensor and display for swimmer	Achieved
MTBF	To be determined by TECHEVAL	182.5 hrs.
MTFL	To be determined by TECHEVAL	2.07 min.
MTTR	To be determined by TECHEVAL	7.16 min.
Turnaround Time	1 hr.	26 min.
Reaction Time	30 min.	44.4 min. This exceeds required time but it is considerably lower than when TECHEVAL began. It is felt that this requirement will be met by the end of OPEVAL
Operational Availability	Not specified in requirements Documents	.990

TABLE 6 USE RECORD OF INDIVIDUAL DIVING UNITS

UNIT NO.	TOTAL DIVES	BOTTOM TIME (HOURS)	MAINT. ACTIONS
OPERATIONAL UNITS			
1	50	73.5	48 min. 19 sec.
2	57	107	16 min. 27 sec.
3	81	131	49 min. 40 sec.
4	87	109.5	10 min. 45 sec.
5	21	70.5	15 min.
6	21	70.5	49 min. 47 sec.
7	18	54.5	29 min. 35 sec.
8	18	64.5	31 min. 01 sec.
STANDBY UNITS			
9	6	14	00
10	2	1.5	1 hr. 15 min.
TOTALS	361	696.5	6hrs. 25 min. 34 sec.